

PHASE II FLIGHT SAFETY DATA PACKAGE FOR THE ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

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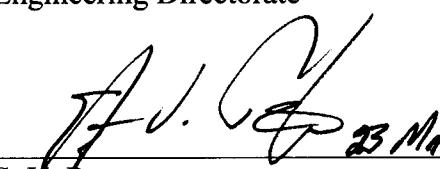
Lyndon B. Johnson Space Center
Houston, Texas

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FOR THE
ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)

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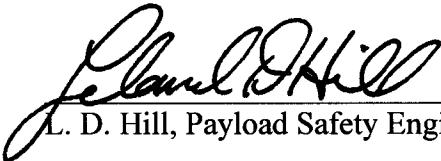
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

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**PHASE II FLIGHT SAFETY DATA PACKAGE
FOR THE
ALPHA MAGNETIC SPECTROMETER-02 (AMS-02)**

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ACRONYMS AND ABBREVIATIONS

α	Absorptivity
A	Amp or Amps
ACC	Anti-Coincidence Counters
AFD	Aft Flight Deck
AI	Action Item
Al	Aluminum
AMICA	Astro Mapper for Instrument Check of Attitude
AMS	Alpha Magnetic Spectrometer
APCU	Assembly Power Converter Unit
APO	AMS Program Office
ASTC	AMICA Star Tracker Camera
atm	atmosphere
AWG	American Wire Gauge
BCE	Battery Charger Electronics
BFS	Backup Flight System
BMS	Battery Management System
BOL	Beginning of Life
BD	Burst Disk or Bursting Disk
Bps	Bits per second

ACRONYMS AND ABBREVIATIONS

μCi	micro Currie
C	Celsius
CAB	Cryomagnet Avionics Box
CAN	Controller Area Network
CAS	Common Attach System
cc	Cubic Centimeter
CCD	Charged Coupling Device
CCEB	Cryocooler Electronics Box
CCR	Crew Consensus Report
CCS	Cryomagnet Current Source
CCSC	Cryomagnet Control and Signal Conditioning
CDC	Cool Down Circuit
CDD	Cryomagnet Dump Diode
CFRC	Carbon Fiber Reinforced Composite
CFRT	Carbon Fiber Reinforced Thermoplastic
CGS	Carlo Gavazzi Space
CGSE	Cryomagnet (or Cryogenic) Ground Support Equipment
CHX	Cold Heat Exchanger
CLA	Capture Latch Assembly
cm	Centimeter
CMG	Control Moment Gyro
CO_2	Carbon Dioxide
CPU	Central Processing Unit

ACRONYMS AND ABBREVIATIONS

CRES	Corrosion Resistant Steel
CRISA	Computadoras, Redes e Ingeniería SA
CSP	Cryomagnet Self Protection
CSR	Customer Support Room
CU	Copper
DC or dc	Direct Current
DDRS	Digital Data Recording System
DLCM	Direct Liquid Content Measurement Device
DOE	Department of Energy
DOL	Discrete Output Low
DV	Digital (on/off) Valve
ϵ	Emissivity
E	Energy
e^+	positron
e^-	electron
EA	Engineering Directorate
EBCS	External Berthing Camera System
ECAL	Electromagnetic Calorimeter
EHV	ECAL High Voltage
ELV	Expendable Launch Vehicle

ACRONYMS AND ABBREVIATIONS

EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESCG	Engineering and Sciences Contract Group
ESMD	Exploration Systems Mission Directorate
EOL	End of Life
ETH	Eidgenossische Technische Hochschule
EVA	Extravehicular Activity
F	Fahrenheit
Fe ⁵⁵	Iron 55
FoV	Field of View
FPGA	Field Programmable Gate Array
FRGF	Flight Releasable Grapple Fixture
γ	Gamma Ray
G	Gauss
GeV	Giga Electron Volts
GFE	Government Furnished Equipment
GFRP	Glass Fiber Reinforced Polymer
GN&C	Guidance, Navigation and Control
GND	Ground
GPC	General Purpose Computer
GPS	Global Positioning System

ACRONYMS AND ABBREVIATIONS

G _{rms}	Gravity Root Mean Square
GSE	Ground Support Equipment
GSFC	Goddard Spaceflight Center
HBE	Hans Bieri Engineering
$\overline{\text{He}}$	Anti-helium
HP	Heat Pipe
HR	Hazard Report
HRDL	High Rate Date Link
HV	High Voltage
Hz	Hertz
IA	Implementing Agreement
ICD	Interface Control Document
ID	Inside Diameter
I/F	Interface
IFM	In-flight Maintenance
IR	Infra-Red
ISIS	International Subrack Interface Standard
ISS	International Space Station
ISSP	International Space Station Program
ITS	Integrated Truss Segment

ACRONYMS AND ABBREVIATIONS

JS	Jacobs Sverdrup
JSC	Johnson Space Center
K	Kelvin
KeV	Kilo Electron Volts
kg	Kilograms
kN	Kilo Newton
KSC	Kennedy Space Center
kW	Kilowatt or Kilowatts
L	Liter (also l)
LBBX	Laser Beampoint Box
LCC	Launch Commit Criteria
LCC	Launch Control Center
LCL	Latching Current Limiter
LCTL	Laser Control Box
LDDR	Laser Diode Driver
LED	Light Emitting Diode
LFCR	Laser Fiber Coupler
LHFP	Liquid Helium Fill Port
LHP	Loop Heat Pipe
LTOF	Lower Time of Flight

ACRONYMS AND ABBREVIATIONS

μm	Micrometer
m	meter
mm	millimeter
MAGIK	Manipulator Analysis, Graphics and Integrated Kinematics
Mbps	Megabits per second
MCA	
MCC	Mission Control Center
MCC	Main Control Computer
MDC	Main Data Computer
MDP	Maximum Design Pressure
MDP	Maximum Dynamic Pressure
MET	Mission Elapsed Time
MHT	Main Helium Tank
MIT	Massachusetts Institute of Technology
MJ	Mega Joules
MLI	Multi-layer Insulation
MMOD	Micro-Meteoroid and Orbital Debris
MOSFET	Metal-Oxide-Silicon Field Effect Transistor
MV	Manually-actuated Valve
NaF	Sodium Fluoride
NASA	National Aeronautics and Space Administration

ACRONYMS AND ABBREVIATIONS

NBL	Neutral Buoyancy Laboratory
NbTi	Niobium Titanium
NSTS	National Space Transportation System
OD	Outside Diameter
OFHC	Oxygen Free High Conductivity
OHP	Oscillating Heat Pipe
OIU	Orbiter Interface Unit
P	Photon
p ⁺	proton
p ⁻	anti-proton
P&I	Process and Instrumentation
PAS	Payload Attach System
PCS	Portable Computer System
PDA	Payload Disconnect Assembly
PDIP	Payload Data Interface Panel
PDS	Power Distribution System
PEDS	Passive Electrical Disconnect System
PEEK	Polyetheretherketone
PFR	Portable Foot Restraint
PFTE	Teflon TM
PGSC	Payload and General Support Computer

ACRONYMS AND ABBREVIATIONS

PGT	Pistol Grip Tool
PIP	Payload Integration Plan
PLB	Payload Bay
PMMA	Polymethyl Methacrylate (Plexiglas™)
PMT	Photo Multiplier Tube
PO	Payload Organization
POCC	Payload Operations Control Center
PPS	Passive Phase Separator
PRLA	Payload Retention Latch Assembly
PSE	Payload Safety Engineer
psi	Pounds per Square Inch
psia	Pounds per Square Inch, Absolute
psid	Pounds per Square Inch, Differential
PSRP	Payload Safety Review Panel
PVGF	Power Video Grapple Fixture
ρ	Density
RHV	RICH High Voltage
RICH	Ring Imaging Cerenkov Counter
RITF	Receiving Inspection Test Facility
ROEU	Remotely Operated Electrical Umbilical
RPCM	Remote Power Control Module

ACRONYMS AND ABBREVIATIONS

RWTH	Rheinisch-Westfälischen Technischen Hochschule (University of Technology)
μsec	microsecond
S3	Starboard 3 (Truss Designation)
SCL	Space Cryomagnetics Limited
SCL	Super Cooling Loop
SDP	Safety Data Package
SFHe	Superfluid Helium (He^{II})
SHV	TOF/ACC High Voltage
SiO_2	Silicon Dioxide
Si_3N_4	Silicon Nitride
SOC	State of Charge
SRMS	Shuttle Remote Manipulator System
SSP	Space Shuttle Program
SSP	Standard Switch Panel
SSPC	Solid State Power Controller
SSPF	Space Station Processing Facility
SSRMS	Space Station Remote Manipulator System
STA	Structural Test Article
STADCO	Standard Tool & Die Company
STD	Standard
STS	Space Transportation System

ACRONYMS AND ABBREVIATIONS

SVP	Structural Verification Plan
TAS	Tracker Alignment System
TBD	To Be Determined
TBR	To Be Resolved
TCS	Thermal Control System
Te	Tellurium
TeV	Tera Electron Volts
Ti	Titanium
Tm ²	Tesla-Meter Squared
TMP	Thermo-Mechanical Pump
TPG	Thermal Prolytic Graphite
TOF	Time Of Flight Counters
TRD	Transition Radiation Detector and associated Gas System
TTCB	Tracker Thermal Control Box
TTCE	Tracker Thermal Control Electronics
TTCS	Tracker Thermal Control System
UMA	Umbilical Mechanism Assembly
UPS	Uninterruptible Power Supply
USCM	Universal Slow Control Module
USS-02	Unique Support Structure-02
UTOF	Upper Time of Flight Counters

ACRONYMS AND ABBREVIATIONS

V	Volt or Volts
VC	Vacuum Case
VCL	Vapor Cooled Leads
VCS	Vapor Cooled Shields
VME	VERSAmodule Eurocard
W	Watt or Watts
WIF	Worksite Interface Fixture
WSA	Worksite Assessment
Xe	Xenon

APPLICABLE SAFETY DOCUMENTS

NSTS 1700.7B	Safety Policy and Requirements for Payloads Using the Space Transportation System
NSTS 1700.7B ISS Addendum	Safety Policy and Requirements for Payloads Using the International Space Station
NSTS/ISS 13830C	Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle/International Space Station
NSTS/ISS 18798B	Interpretations of NSTS/ISS Payload Safety Requirements
JSC 26943	Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports for Payloads Using the Space Shuttle

1. INTRODUCTION

This Phase II Flight Safety Data Package for the Alpha Magnetic Spectrometer-02 (AMS-02) is submitted in response to the safety requirements of NSTS 1700.7B, "Safety Policy and Requirements for Payloads Using the Space Transportation System", and NSTS 1700.7B, ISS Addendum, "Safety Policy and Requirements for Payloads Using the International Space Station. This safety package has been prepared in accordance with NSTS/ISS 13830C, "Payload Safety Review and Data Submittal Requirements for Payloads Using the Space Shuttle/International Space Station". Also, JSC 26943, "Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports for Payloads Using the Space Shuttle", was used as a guideline document.

2. SCOPE

This safety data package contains the safety analysis performed for the AMS-02 Payload flight hardware and the flight operations of the AMS-02 mission. The major subsystems of the AMS-02 included in this safety analysis are listed below. Each subsystem and the operational scenarios will be discussed in detail in Section 5 of this safety data package.

- Cryogenic Superconducting Magnet (Cryomag)
- Unique Support Structure – 02 (USS-02) with integral Vacuum Case (VC)
- Transition Radiation Detector and associated Gas System (TRD)
- Time-of-Flight (TOF) Scintillator Assemblies
- Silicon Tracker
- Tracker Alignment System (TAS)
- Anti-Coincidence Counters (ACC)
- Ring Imaging Cerenkov Counter (RICH)
- Electromagnetic Calorimeter (ECAL)
- Star Tracker
- Global Positioning System (GPS)

- Data and Interface Electronics
- Thermal Control System (TCS)
- Micrometeoroid and Orbital Debris (MMOD) Shields
- Payload Attach System (PAS) (Passive Half)
- Digital Data Recording System – 02 (DDRS-02)
- Space Shuttle Program (SSP) and ISS Program (ISSP) Provided Hardware
 - Flight Releasable Grapple Fixture (FRGF) SSP
 - Remotely Operated Electrical Umbilical (ROEU) SSP
 - Power Video Grapple Fixture (PVGF) ISSP
 - Umbilical Mechanism Assembly (UMA) (passive half) ISSP
 - External Berthing Camera System (EBCS) ISSP

The AMS-02 Payload also requires the use of the Shuttle Remote Manipulator System (SRMS) and the Space Station Remote Manipulator System (SSRMS) for removing the payload from the Orbiter Cargo Bay and berthing it on the station. The payload requires an active PAS and an active UMA, which are ISS hardware and part of the Integrated Truss Segment (ITS). The safety analyses for the SSP and ISS provided hardware are not included in this data package. However, the safety of the use and interfaces of the SSP and ISS provided hardware with the AMS-02 Payload are a part of this AMS-02 safety data package.

3. PURPOSE

The purpose of this safety analysis is to identify potential flight hazards associated with the AMS-02 Payload design and operation; to evaluate their cause and impact on the Space Shuttle, Orbiter, ISS, and flight crews; to define methods for eliminating or controlling the hazards; to verify the elimination or control methods; and to document the status of the verification methods. This safety package is intended to provide the information necessary for a Phase II review of the AMS-02 Payload by the JSC Payload Safety Review Panel (PSRP).

4. AMS-02 PROJECT OVERVIEW

The AMS-02 experiment is a state-of-the-art particle physics detector being designed, constructed, tested and operated by an international team organized under United States Department of Energy (DOE) sponsorship. The AMS Experiment will use the unique environment of space to advance knowledge of the universe and potentially lead to a clearer understanding of the universe's origin. Specifically, the science objectives of the AMS are to search for antimatter (anti-helium and anti-carbon) in space, to search for dark matter (90% of the missing matter in the universe) and to study astrophysics (to understand Cosmic Ray propagation and confinement time in the Galaxy).

4.1 AMS-02 EXPERIMENT

The AMS-02 Experiment utilizes a large cryogenic superfluid helium (SFHe @ 2° K) superconducting magnet (Cryomag) to produce a strong, uniform magnetic field (~ 0.8 Tesla) within the interior of the magnet. The experiment has planes of detectors above, in the center of, and below the magnet (Figures 4.1-1 and 4.1-2). Electrically charged particles will curve when they pass through the magnetic field. Particles made of matter will curve one way, and those of antimatter will curve the opposite way. The positions of electrons released as the charged particles pass through the detectors will be electronically recorded (Figure 4.1-3). Physicists will be able to study the trajectory of curvature and determine the charge of the particles from the direction of curvature. They will also be able to determine the mass of the particles from the amount of curvature. They will then be able to tell whether it was matter or antimatter.

An Implementing Arrangement (IA) between NASA and DOE signed in September 1995 established two flights for AMS: an Engineering Test on Shuttle (STS-91 – June 1998) and a 3-year Science Mission on ISS (Launch Ready September 2007 – Date under review). The flight of AMS-01 was a precursor flight of the detectors proposed for AMS-02. AMS-01 utilized a permanent magnet in place of the cryomagnet. The purpose of the precursor flight was to verify operation of the AMS experiment, verify command and data communications, collect thermal data for the ISS flight, determine actual

accelerations on some AMS internal instruments and establish experimental background data.

The AMS-02 will be transported to the International Space Station (ISS) in the cargo bay of the Space Shuttle (Figure 4.1-4) for installation on the external truss of the ISS (Figures 4.1-5 and 4.1-6). The AMS-02 is scheduled to remain on the ISS for at least three operational years of data collection. Due to limited space shuttle flights, AMS-02 is not scheduled to return to Earth and will remain on the ISS.

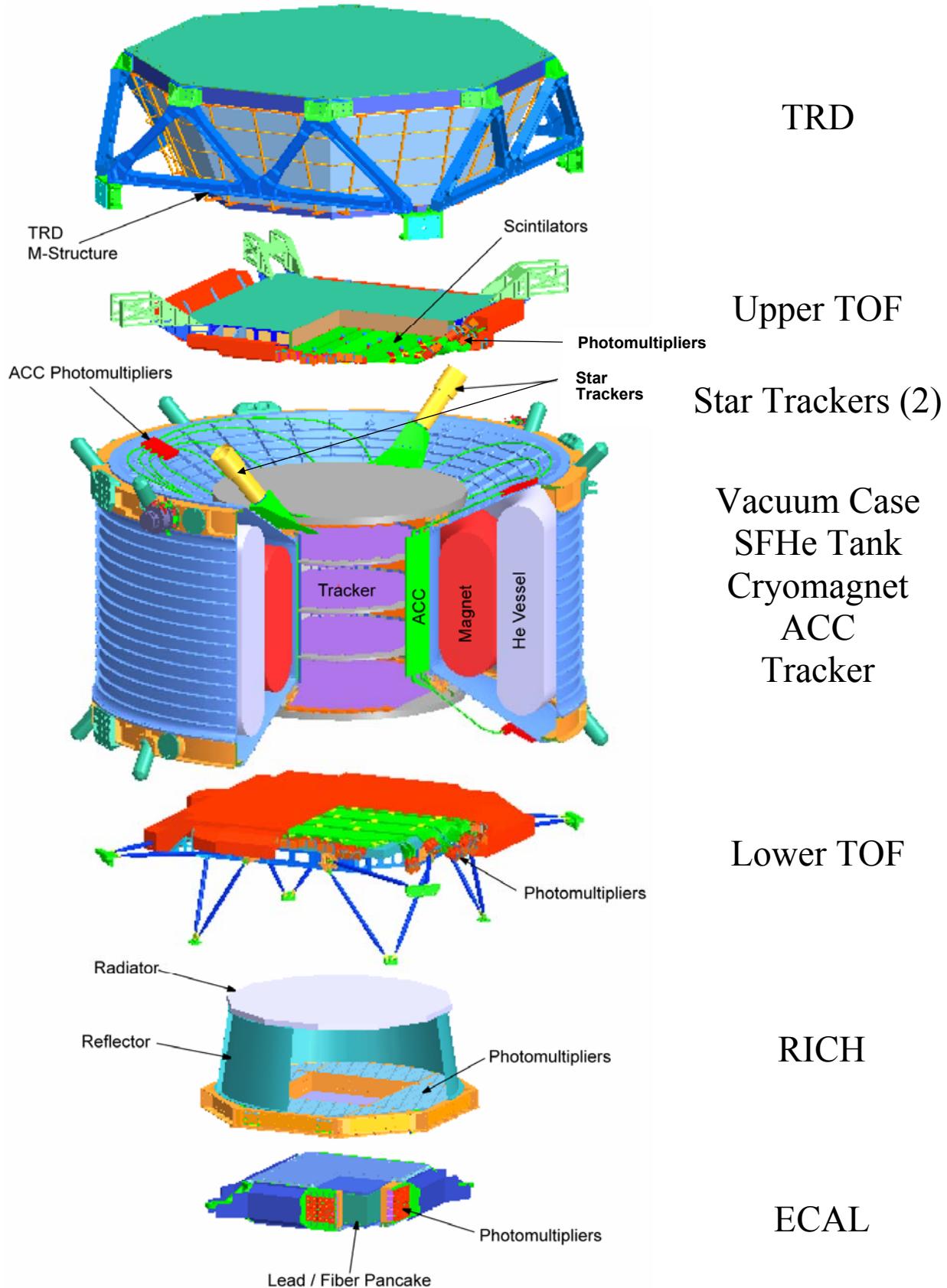
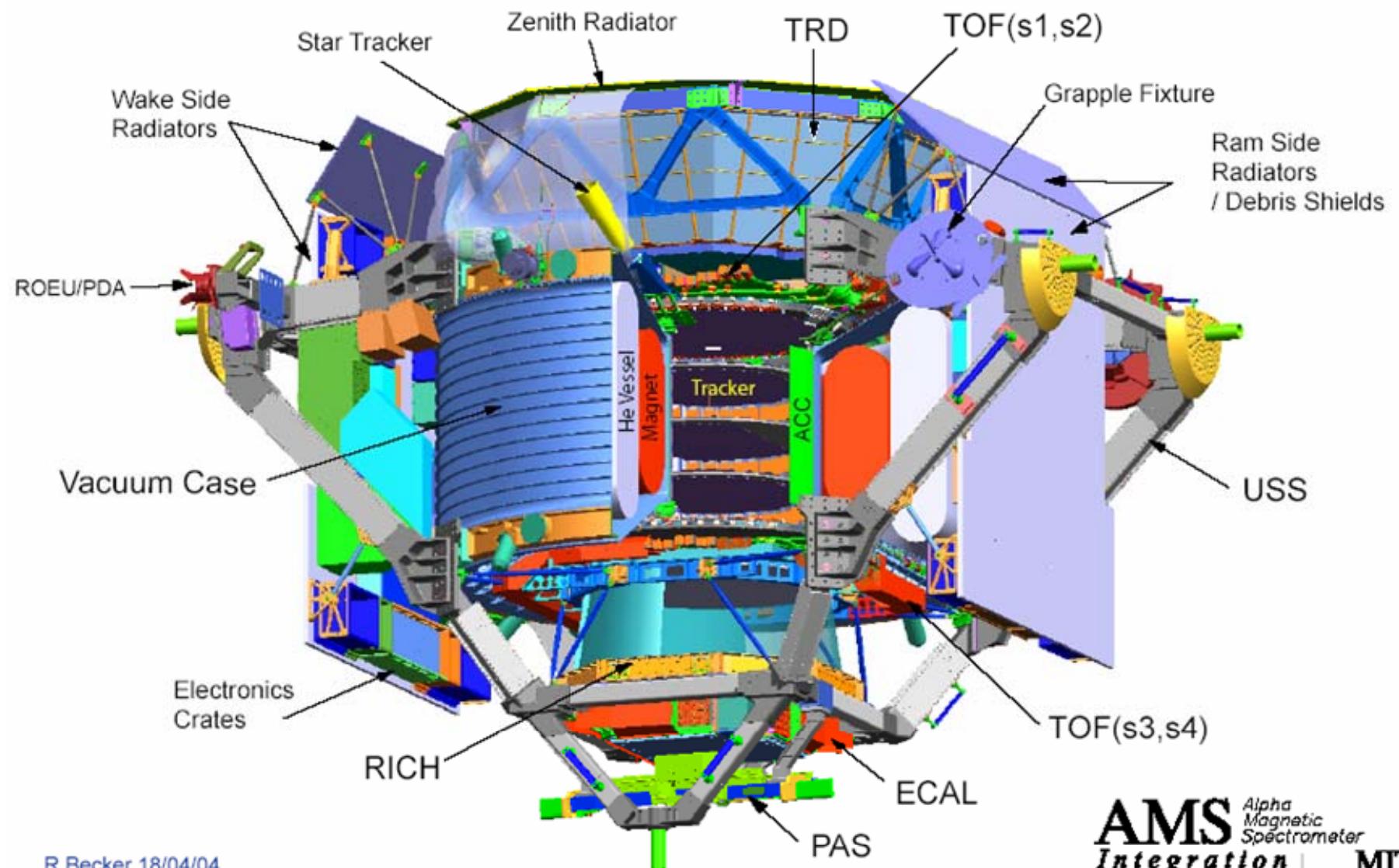


Figure 4.1-1 The AMS-02 Experiment

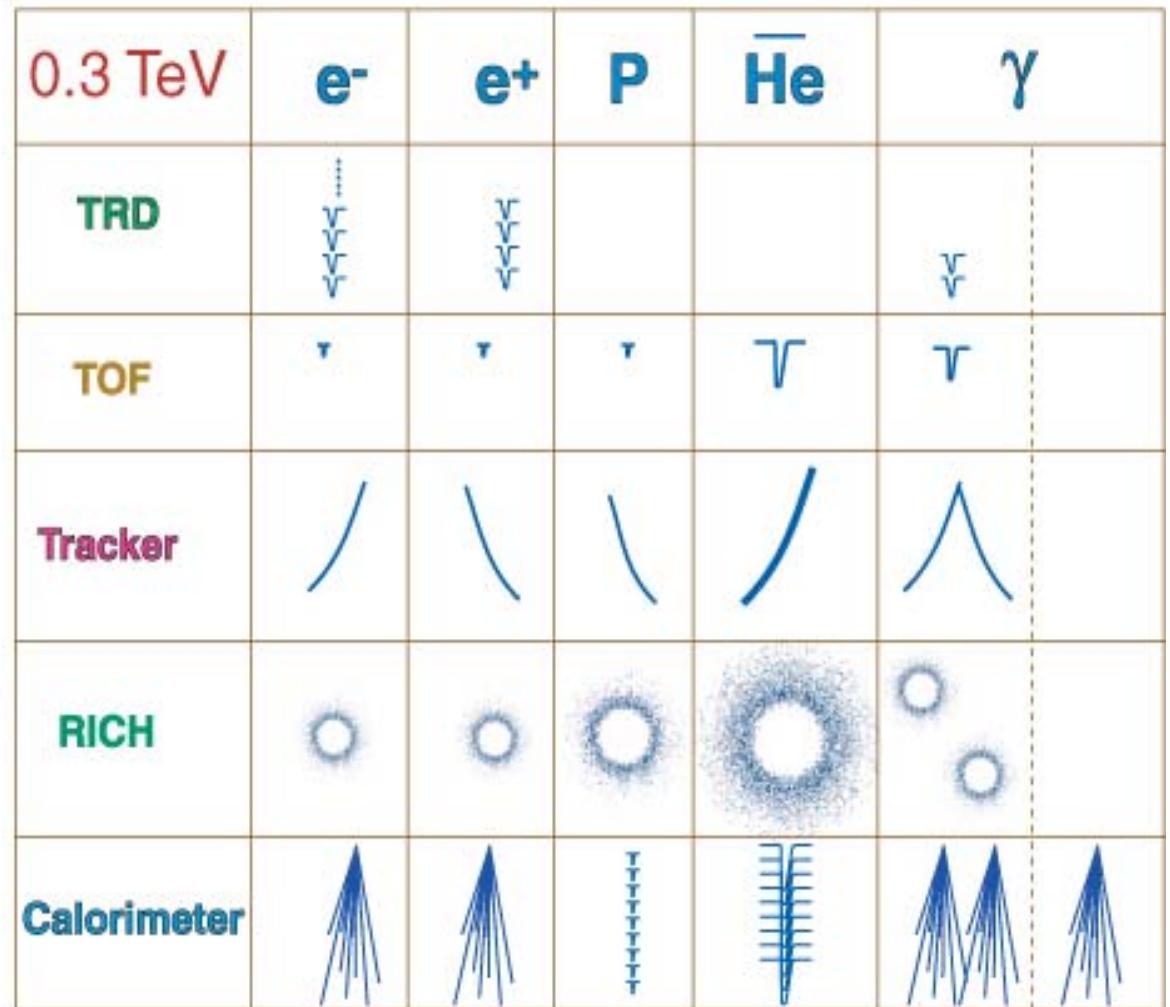
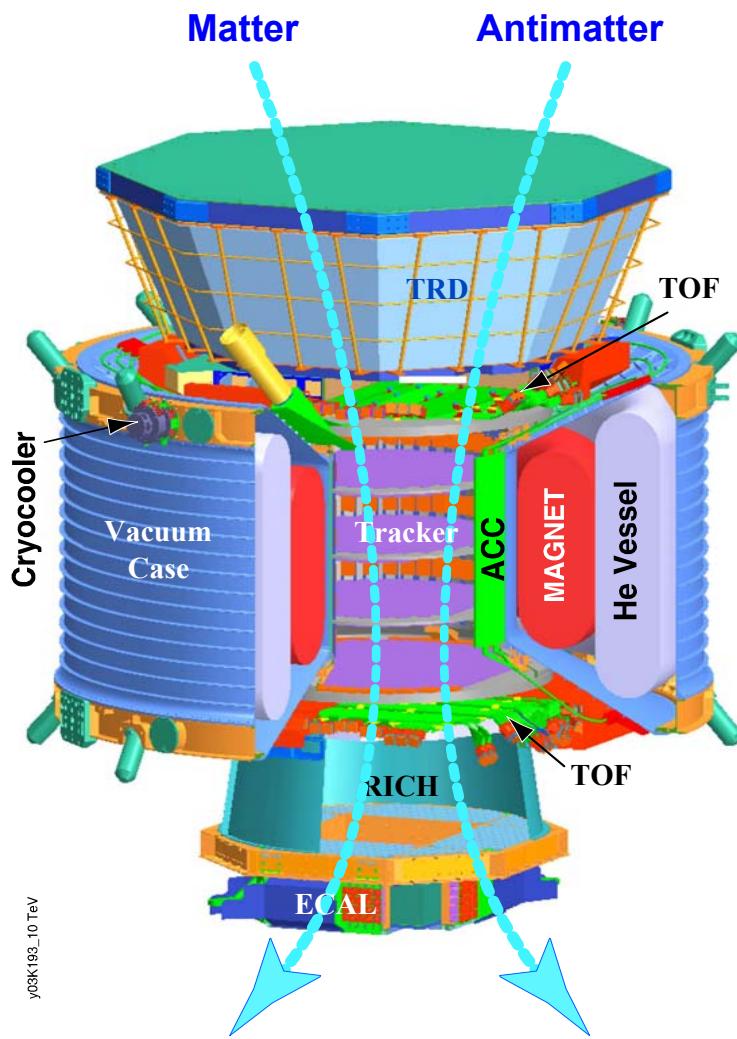


R.Becker 18/04/04

AMS Alpha Magnetic Spectrometer
Integration | MIT

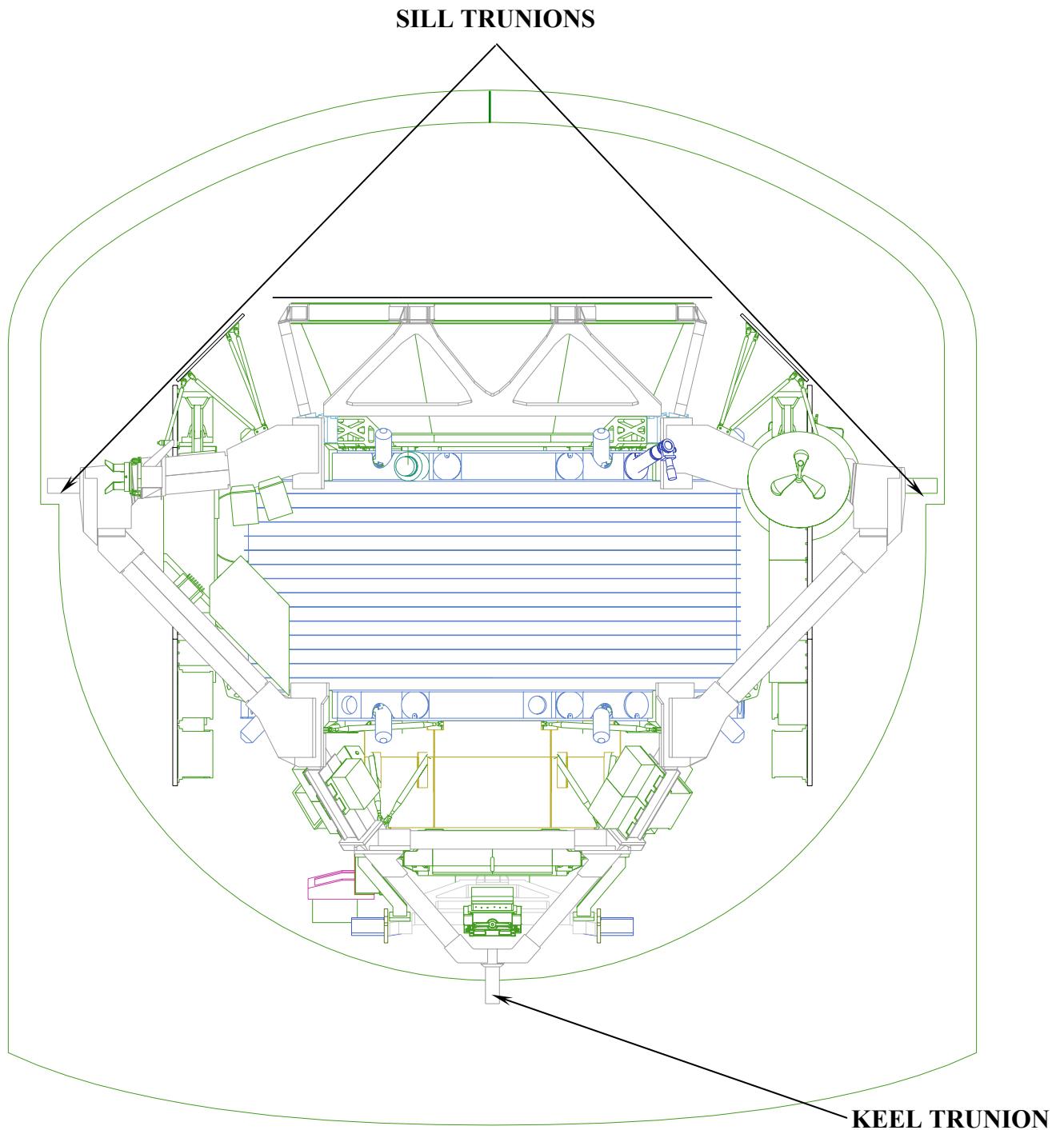
Figure 4.1-2 The AMS-02 Payload

AMS: A TeV Magnetic Spectrometer in Space



300,000 channels of electronics $\Delta t = 100$ ps, $\Delta x = 10\mu$

Figure 4.1-3 AMS-02 Detector Signatures



**Figure 4.1-4 AMS-02 in the Space Shuttle Orbiter Cargo Bay
(From forward bulkhead looking aft.)**

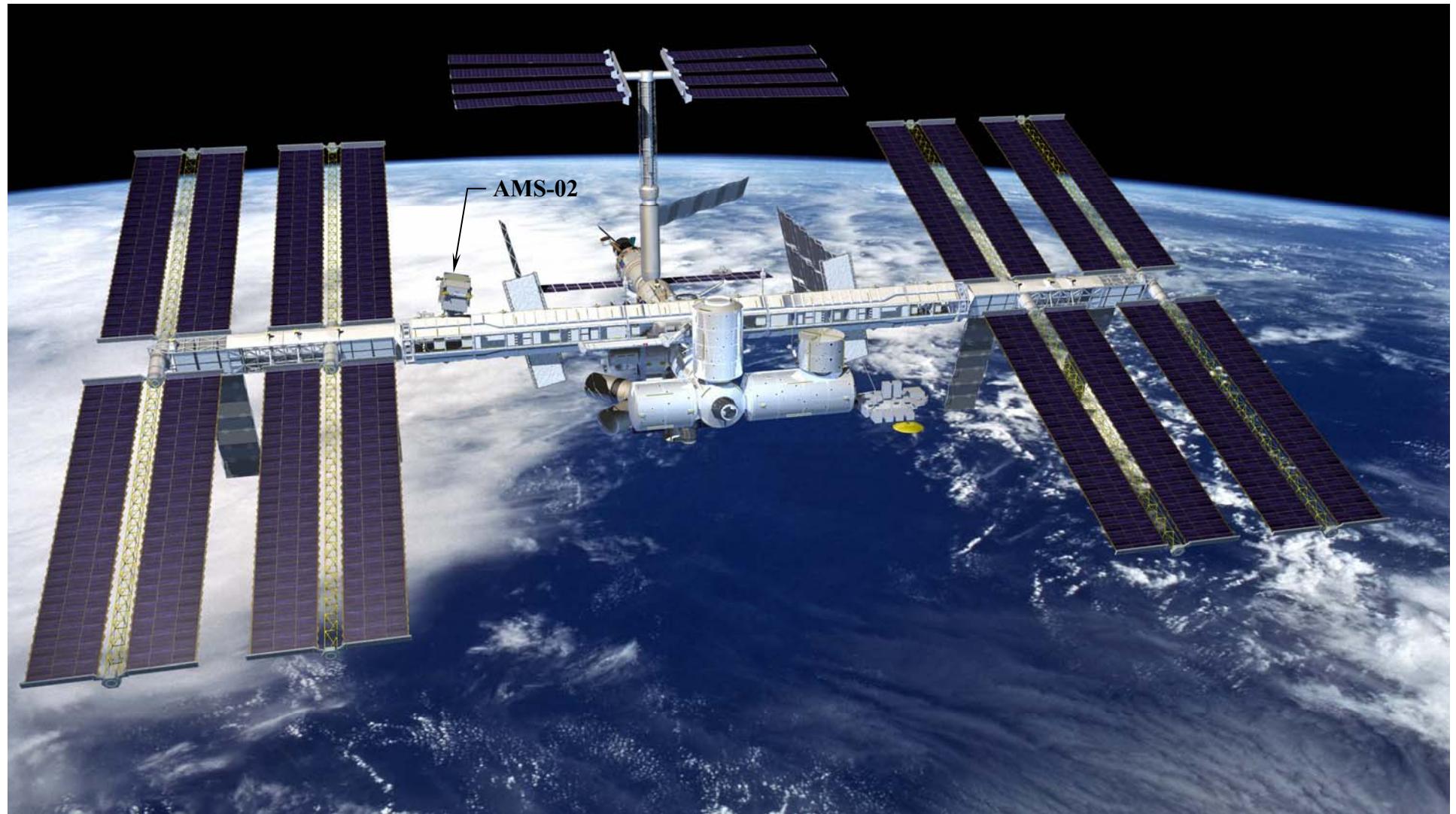


Figure 4.1-5 AMS-02 on the ISS

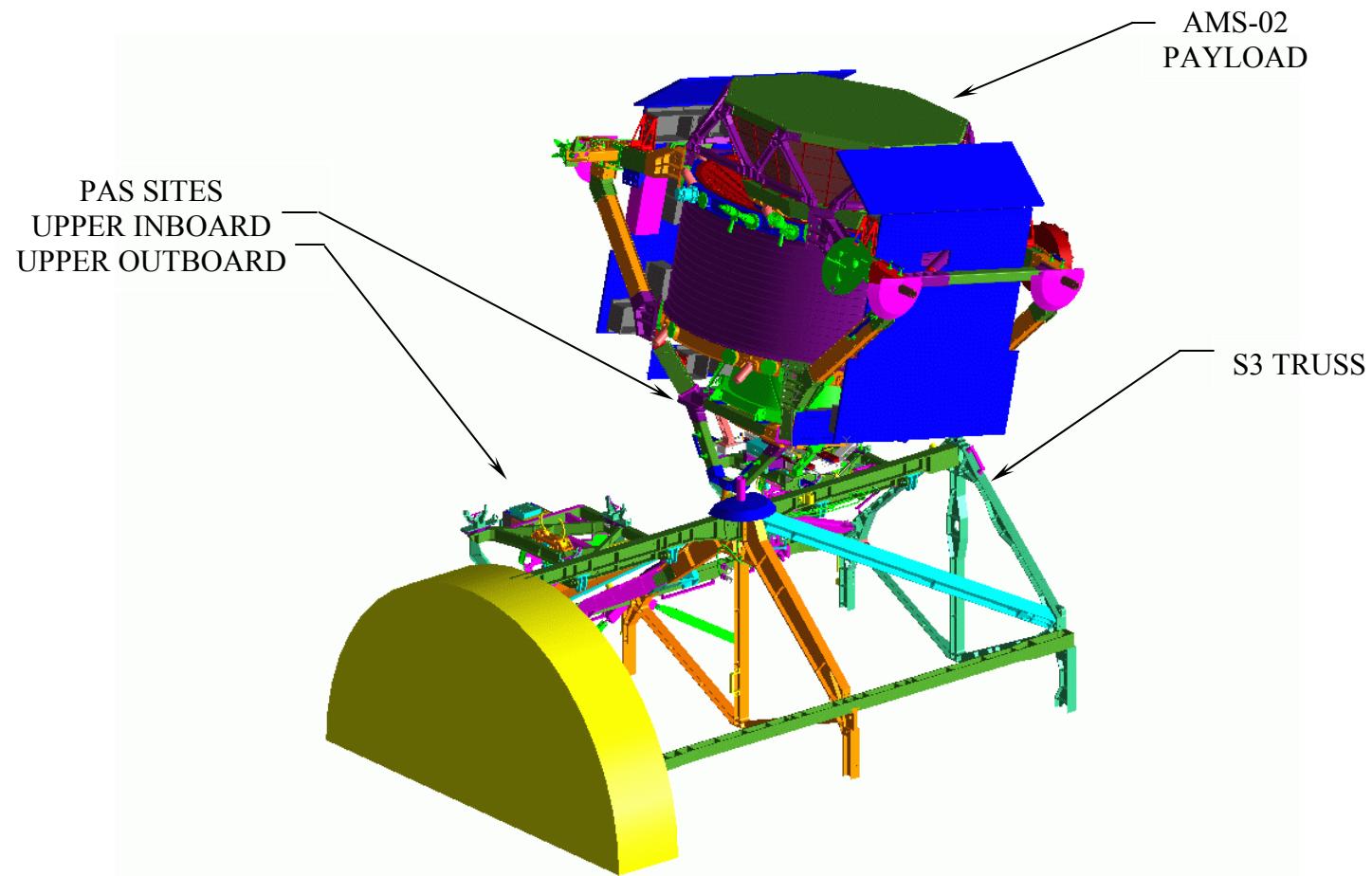


Figure 4.1-6 AMS-02 Payload Assembly on ISS S3 – Z Inboard PAS Site

4.2 AMS-02 ROLES AND RESPONSIBILITIES

The Implementing Arrangement (IA) between the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA) establishes the roles and responsibilities of DOE and NASA with respect to the Alpha Magnetic Spectrometer (AMS) Program.

4.2.1 NASA Responsibilities

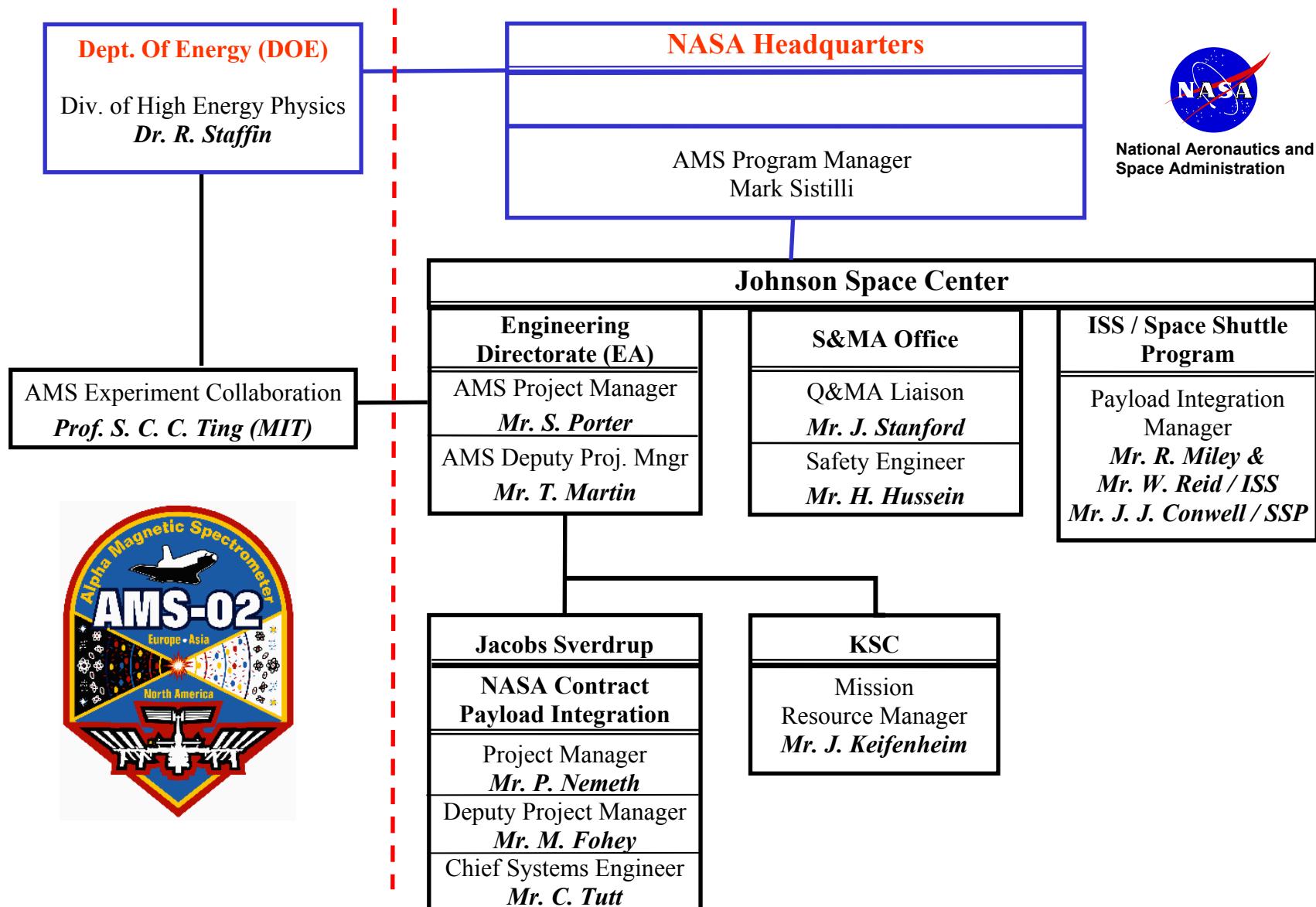
NASA Headquarters is responsible for the overall NASA management of the AMS Program interface activity between NASA and DOE and for overall program management of the NASA activities required to support the implementation of the flight of AMS-02 (Figure 4.2.1-1). The AMS Project Office (APO) of the Engineering Directorate (EA) at JSC has been assigned responsibility for implementing the AMS Program. The APO serves as the AMS representative and acts as the single point of contact between the AMS Program and the Shuttle and ISS Programs. The APO reports and is responsible directly to NASA Headquarters and is the AMS NASA representative to all other NASA organizations providing equipment, materials, and services to the AMS Program.

In order to implement the AMS Program, NASA will perform or provide the following:

- Fly the AMS-02 on the ISS as an external attached payload, and provide accommodation on the ISS; all necessary services, AMS-to-carrier integration, AMS transfer to and installation on the ISS. NASA shall include the AMS-02 in the Space Station utilization planning process.
- Provide mission-peculiar interface hardware and software for the AMS-02 on the ISS.
- Perform AMS-to-carrier integration support, payload certification, and payload safety certification.
- Provide necessary facilities and perform related services for the AMS-02 final assembly, testing and checkout at the launch site, as well as control center accommodations for AMS-02 operation and monitoring as required for the launch and transfer-to-ISS phases.

- Provide AMS-02 housekeeping, science (unprocessed) and carrier-ancillary data products to the DOE-sponsored team at the designated NASA data handling/distribution center.
- Perform a mission management function consisting of the following tasks in support of AMS:
 - Representation of the AMS to the Shuttle Program, the ISS Program, and to various supporting NASA organizations involved in the integration and flight of AMS.
 - Design and operations consulting and guidance to the AMS Program to minimize the potential for incorporation into the AMS design of features or characteristics which could result in functional and/or safety incompatibilities with either the Shuttle or the ISS or with ground systems at the launch or landing sites.
 - Performance of detailed engineering analyses (e.g. stress, loads, etc,) to ensure compatibility of the AMS with the Shuttle and ISS through its launch, operational, and return environments.
 - Systems engineering for the development of mission-peculiar interface hardware and software needed to analytically, physically, and operationally integrate the AMS into the Shuttle and ISS system.
 - Management of the physical integration of the AMS and mission-peculiar interface hardware onto the Shuttle and ISS carriers.
 - Guidance, identification and control of hazards, and lead role in development of Safety Compliance Documentation, and representation of AMS to the Shuttle, ISS, and KSC Safety Panels.
 - Guidance in the development of requirements levied on the Shuttle and ISS and lead role in negotiation of those requirements through the Shuttle Payload Integration Plan, (PIP), the ISS PIP, the associated annexes, and required Interface Control Documents (ICDs).
 - Provision of training related to Shuttle and Station operations, including the development of training requirements.
 - Provision of documentation required for payload verification of AMS compliance with Shuttle and ISS program requirements.
 - Representation of the AMS Program at KSC and support of testing, AMS-to-carrier integration, and flight operations.
 - Real-time mission support for the delivery flight to the ISS, through AMS deployment, installation, checkout, and verification of proper operation as

well as continued support through mission life as necessary to ensure mission success.



National Aeronautics and Space Administration

Figure 4.2.1-1 AMS Project Functional Organization

Flight hardware to be provided by NASA/APO is listed in Table 4.2.1-1.

TABLE 4.2.1-1 NASA/APO PROVIDED FLIGHT HARDWARE

ITEM	UNITS
* External Berthing Camera System (EBCS), w/cables and brackets	1
* EVA (Extravehicular Activity) Handrails/ Tether Attach Points	9
* Flight Releasable Grapple Fixture (FRGF), w/cables and brackets	1
* Portable Foot Restraint (PFR) Worksite Interface Fixture (WIF)	1 (or 2 if required by ROEU redesign)
* Power Video Grapple Fixture (PVGF), w/cables and brackets	1
* Remotely Operated Electrical Umbilical (ROEU)/Payload Disconnect Assembly (PDA), w/cables and brackets	1
* Umbilical Mechanism Assembly (UMA) (Passive Half), w/cables and brackets	1
Cryomagnet Vacuum Case (VC) (Flight Article)	1
Micrometeoroid and Orbital Debris (MMOD) Shields	2
Payload Attach System (PAS) (Passive Half)	1
EVA Interface Panel (Interface to UMA)	1
Interface Panel A (Interface to ROEU)	1
Cabling from interface panels to J-Crate and PDS	as required
DDRS-02 and associated cabling/interface cards	1
Trunnion scuff plates for deployable payload	4 (Part of USS-02)
Thermal Blankets	6
Unique Support Structure-02 (USS-02)	1

* Items (excluding brackets) supplied by NASA SSP or ISSP and integrated into AMS Payload by NASA/APO.

4.2.2 DOE Responsibilities

The DOE Headquarters Division of High Energy Physics, under the Department's Office of Energy Research is responsible for the administration of a Cooperative Agreement with the Massachusetts Institute of Technology (MIT) for a basic science program in particle physics. Under this agreement, the MIT Principle Investigator for the AMS Program has organized, and is the spokesman for, the AMS International Collaboration, currently consisting of over 200 physicists from 16 countries, to implement its part in the AMS Project (Figure 4.2.2-1). The DOE or, as appropriate, its MIT Cooperative Agreement Principle Investigator, will be responsible for: the definition, design, and development of the AMS hardware and related ground support equipment (GSE); delivery to and return from a location to be specified at the Kennedy Space Center (KSC) for integration or de-integration in the NASA processing system; and establishment of the science mission requirements. These responsibilities will include:

- All necessary interagency coordination and obtaining necessary concurrences within the U.S. Government for the AMS Project regarding international arrangements among the DOE Program Collaborators involved in the definition, design, development, fabrication, assembly, test, checkout, and operation of the AMS.
- Management of all international transfer and shipment, unless otherwise agreed. This includes, but is not limited to, customs clearances, import and export licenses required for AMS systems, subsystems, or components, or, as mutually agreed, for any NASA tests, integration, or mission-peculiar equipment or technical data that is required to be shipped abroad.
- Establishment of the AMS science plan, including science requirements, definition of data requirements, and definition of mission success criteria.
- Provision, when requested by NASA, of DOE technical and management support for all formal NASA reviews involving AMS (Safety Reviews, Cargo Integration Reviews, Ground Operations Reviews, Flight Operations Reviews, etc.) and other related NASA reviews and activities.
- Development and management of an AMS implementation schedule consistent with NASA program milestone schedules and provision of updates to keep NASA advised of AMS schedule status.
- Provision of technical and management data required by NASA to complete programmatic requirements (e.g. Safety, ICDs, MIP, reviews, material lists, etc.).

- Provision of all transport equipment (shipping containers, other AMS handling ground support equipment) required for AMS transport to and from NASA KSC.
- Management of: (1) All AMS science and engineering team activities, including travel, visa issuances, and related in-country logistical expenses; (2) support for science operations before, during, and after AMS flights; and (3) science data analysis, distribution, and publication.

Flight hardware to be provided by DOE/MIT is listed in Table 4.2.2-1.

TABLE 4.2.2-1 DOE/MIT PROVIDED FLIGHT HARDWARE

ITEMS	UNITS
Cryomagnet System including SFHe Tank, Non-linear Support Straps, and Cryomagnet Avionics Box (CAB)	1
Transition Radiation Detector and associated Gas System (TRD)	1
TRD Gas System	1
Upper and Lower Time-Of-Flight (TOF) Scintillator Assembly	1 each
AMS-02 Silicon Tracker Assembly	1
Tracker Alignment System (TAS)	1
Anti-Coincidence Counters (ACC)	1
Ring Imaging Cerenkov Counter (RICH)	1
Electromagnetic Calorimeter (ECAL)	1
Thermal Control System (TCS)	1
Star Tracker	2
Global Positioning System (GPS) Receiver	1